

Research Article

Economics and the Adoption of Livestock Vaccination: Analysis and New Insights

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Abstract

This article uses economic principles and theory and draws on the available scholarly literature to examine the economics of vaccinating livestock. After providing relevant information about the nature of livestock vaccines, the implications of economic principles for private decisions and the gains from livestock vaccination are specified. Empirical findings on this topic are assessed and it is demonstrated that the overhead (fixed) costs involved in vaccinating livestock is an important profitability influence on the willingness of livestock owners to vaccinate their livestock. In considering the economics of livestock, it is necessary to go beyond decision making by individual livestock owners. For example, the externality or spillover effects of livestock vaccination can be of economic importance and can justify the adoption of public policies which result in more livestock vaccination regionally or nationally than otherwise would occur. Furthermore, in market economies, the distribution of economic gains between livestock producers and consumers of livestock products depends on the nature of market adjustments. As found, this can result in livestock owners only receiving a small share of the economic benefits from vaccination. Moreover, in some cases, their economic surplus can decline. Desirable areas of future research involving economics and animal health are identified. The importance of combining natural and social science in further studies is identified.

Keywords: Animal health; Decision-making by livestock owners; Economics of vaccinating livestock; Externalities (spillovers) from livestock vaccination; Market adjustments and economic gain from livestock vaccination; Social influences on livestock vaccination

Introduction

Vaccines play an important role in the maintenance of animal health. Vaccines now exist for the prevention or alleviation of a wide range of livestock diseases [1]. Their use, however, is often less than can be justified from an economics point of view, especially from a social or collective perspective. The purpose of this article is to apply economic theory to explain and analyse why this is so and to outline and discuss policies which could be adopted to rectify this situation. In addition, attention will be given to how the economic benefits of livestock vaccination are likely to be shared between owners of livestock and buyers of livestock products in market economies. Depending on the nature of market supply and demand schedules, the distribution of economic gains from livestock vaccination between livestock owners and consumers of livestock products varies. For example, in some cases, due to the operation of the market mechanism, all economic gains from livestock vaccination are obtained by consumers. This result is not immediately obvious.

This article begins with a short discussion of materials and methods used, provide some background information on the nature of vaccines, and then focuses on the economics and the decisions of individual livestock owners about vaccinating their livestock. Private

decisions to vaccinate livestock are liable (in the case of contagious diseases) to result in less vaccination than is desirable from a collective or social point of view for reasons which are outlined. Subsequently, policy measures are outlined that could be used to rectify this situation. Subsequently, division between livestock owners and consumers of livestock products of the economic gains from vaccinating livestock is examined, assuming that livestock products are marketed. This article concentrates only on livestock that are kept for sale of physical products, such as meat, eggs and milk. Animals may be kept for purposes other than this, e.g., as pets.

Materials and Methods

Economic theory is applied to analyse the issues mentioned above and reference is made to previous relevant findings reported in the literature about the economics of livestock vaccination. In particular, the economic theories of private decision-making are applied in order to predict economic influences on the private decisions of livestock owners about the vaccination of their livestock, and this analysis is related to findings reported in the literature.

The economic theory of external effects (externalities) also applied to examine the collective effects of livestock vaccination, their social economic consequences and the desirability of government intervention to increase to extent to which livestock owners vaccinate their livestock.

Standard economic market analysis is utilized to investigate the ways in which the economic benefits from livestock vaccination are shared between livestock owners and consumers of such products if they are marketed. Specifically, comparative static market analysis is used for this purpose. This provides findings which appear to have been given inadequate attention in the available literature.

Background Information about the Nature of Livestock Vaccines

Livestock vaccines have diverse characteristics. The most

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commonly used vaccines are killed or inactivated vaccines which stimulate the production of antibodies. Live vaccines are those which contain living viruses or bacteria that have been weakened [2]. Vaccines have also been developed which contain only viral or bacterial antigens and which trigger immune responses to some diseases such as foot and mouth disease [3]. Live vaccines can stimulate life-long immunity to some diseases when livestock are given a single dose. However, they can have harmful effects on pregnant livestock, e.g. cause abortions, and they lose their potency quickly after being mixed on farm [2]. They may also have other negative side effects at least temporarily, on livestock production, e.g. reduce milk production.

Killed vaccines are more benign but usually require more than one dose to raise the level of protection of livestock against targeted diseases. The first dose may give little immunity and result initially in the production of a low level of antibodies. The second dose (given at a later stage) raises the level of immunity. However, boosters are usually required (for example, annually) to sustain immunity [2]. Therefore, this form of disease prevention involves ongoing expenditures by livestock holders.

Some vaccines provide protection against multiple livestock diseases. These may be more costly to purchase but reduce the number of injections or times vaccines have to be administered and therefore, can reduce the costs of carrying out a vaccination program. Vaccines have been developed both for some non-contagious diseases (e.g., botulism) and for contagious diseases (e.g., foot and mouth disease). Vaccinations against the latter types of diseases have positive environmental externality or spillover effects. In these cases, the more widespread is vaccination against these diseases, the lower is the risk of the disease occurring among livestock that are not vaccinated or are poorly vaccinated. On the other hand, this spillover effect is absent in the case of non-contagious diseases for which vaccines are available.

Because the nature of livestock vaccines is quite varied and so too are the attributes of disease that they are designed to protect against, evaluating the economics of their use can be quite complicated. Nevertheless, simple economic models can be applied to provide significant insights into the private and social optimality of vaccinating livestock.

Private Decisions about Economic Gains from Livestock Vaccination

Applications of economic models

Livestock owners vary in their economic aims. Let us consider the decisions of individual owners who aim to maximize their profit by deciding whether or not to vaccinate their livestock. The expected change in profit of a livestock owner vaccinating his/her livestock can be expressed as

$$B = V - N, \quad (1)$$

Where

B is the owners' expected net gain (or loss) in profit as a result of the vaccination;

V is the owners' expected profit after vaccination and after deducting vaccination costs; and

N is the owners expected profit in the absence of vaccination.

Formula (1) can be made more specific. Let p equal the probability or risk of the occurrence of relevant diseases outbreak among the livestock of an owner. When the livestock are vaccinated let \hat{V}_1

represent the owners' predicted profit from his/her livestock if there is a disease outbreak and \hat{V}_2 represent this if there is not an outbreak. When the owners' livestock are not vaccinated, let \hat{N}_1 indicate the owners' predicted profit in the absence of a disease outbreak and \hat{N}_2 indicate that if there is an outbreak among the owners' livestock. Then expression (1) can be rewritten as

$$B = [\hat{V}_1(1-P) + \hat{V}_2(P)] - [\hat{N}_1(1-P) + \hat{N}_2(P)] \quad (2)$$

Other things being held constant, B , the economic gain from vaccination will be higher, the greater is the risk (p) of the owners' livestock being exposed to the focal disease, the greater is the economic reduction in profit in the absence of vaccination, and the more effective the vaccine is in maintaining the profit obtained from the livestock.

B is the reduction in expected profit avoided as a result of vaccination if it pays to vaccinate. However, it is possible for B to be negative in which case it is unprofitable for an individual livestock owner to vaccinate his or her livestock.

Relationships of the type illustrated in Figure 1 are relevant and these will vary from case to case. In Figure 1, the expected benefit to a farmer of vaccinating his/her livestock (B) as a function of the probability (p) of his/her livestock being exposed to a focal disease is shown by the line ACD supposing that all the other variables in expression (2) are held constant. In this case, point C (corresponding to a probability of disease exposure of p_1) is a threshold value. If the risk of exposure of the livestock to this focal disease exceeds p_1 , it pays to vaccinate, and if it is below p_1 , vaccination is unprofitable. The relationship might not be linear.

For some purposes, a more advanced model of 'profit maximization' can be relevant. This model can be used to take account of the difference which a program of livestock vaccination makes to the capitalized value of the livestock of a farmer. If this approach is adopted, the expected economic profitability of a farmer vaccinating his/her livestock is equal to the expected net present value of his/her livestock if vaccinated less their expected net present value if they are not vaccinated. This is equivalent to their change in capitalized value as a result of vaccination. It applies the profit maximization rule proposed by Hicks [4]. It can be especially useful when a disease causes mortality of livestock. In theory, the change in capitalized value can be decomposed into that due to mortality and that arising from morbidity. Net present value analysis has been used to estimate the economic benefit of vaccination to control bovine brucellosis in Brazil on a state-wide basis [5]. They considered net economic present values for the estimated minimum and maximum effects of the disease on livestock production and for different mortality rates of cattle.

Comments on empirical findings

Although Heffernan et al. [6] found that poorer farmers in Bolivia were less likely to vaccinate their livestock than richer farmers, they concluded that the reasons might be more of a sociological than an economic nature. As a result of an additional study of a sample of 601 poor livestock keeping households in Tamil Nadu State in India, they reinforced this point of view [7]. They concluded that "contrary to conventional wisdom, 'the ability to pay' for vaccination did not appear to be the primary inhibitor to vaccination coverage" [7, p. 116]. While this may be so, further evidence is required before concluding that this is generally so.

Conventionally, one would expect poor owners of livestock to

have little or no surplus income to invest in livestock vaccination because most are caught in a poverty trap. Living close to subsistence level, they may find it difficult or impossible to forgo income to vaccinate their livestock, even if this might be profitable, but with delayed benefits in most cases. Borrowing can also be a problem for poor livestock holders in developing countries when interest rates are high and if they are already in considerable debt.

The findings of Suresh et al. [8] seem to be at odds with those of Heffernan et al. They sampled 998 livestock owners in Rajasthan and analysed the data using logit analysis. They found that the likelihood of a farmer vaccinating his/her bovines (buffalo and cattle) compared to not vaccinating these increased with the value of the farmers' fixed assets associated with livestock production and that this was statistically significant at the 1% level. This was the most statistically significant variable.

They suggest that 'by adopting vaccination, the farmers realise [a] higher rate of returns from their fixed assets' [8, p. 489]. However, it is possible that farmers with more fixed assets were richer farmers and had 'surplus' income. In addition, given that these farmers have higher overhead costs, than farmers with fewer fixed assets, they would suffer larger losses in the event of their livestock not being vaccinated and a disease outbreak is occurring.

Suresh et al. [8] also found that crossbred cattle were more likely to be vaccinated than local breeds of cattle. This was ascribed to crossbred cattle being more susceptible to disease than local cattle [8, p. 487]. They also reported that the number of bovines that a farmer had was not a statistically significant determinant of whether they were vaccinated.

On the other hand, Battacharya et al. [9] undertook a study of factors influencing the adoption of *Trichomoniasis* vaccine by Nevada Range cattle producers in the United States, and applied a multinomial logit model to their data. They found that the probability of not using the vaccine fell with herd size [9, p. 188]. They do not indicate why but one possible reason could be that there are economies of scale in administering the vaccine, that is, the cost per animal declines as the number of cattle vaccinated on a property increases. The cost of administering a vaccine usually involves both overhead (fixed) costs and variable costs.

The influence of the fixed or overhead cost on the profitability of vaccinating herds or flocks of animals varies with the herd or flock size. This is illustrated by Figure 2. In this figure, the line, ABC represents the average variable cost of vaccinating animals (cost) as a function of the number of animals needing to be vaccinated on a property, and the curve marked HJFK is the total cost per animal vaccinated. The distance between lines HJFK and ABC indicates the overhead (fixed) cost per animal vaccinated. It forms a rectangular hyperbole. The line marked DEFG is assumed to represent the average economic benefit of vaccinating each animal in the herd or flock. It is shown as being constant, but it need not be. The difference between line DEFG and the curve HJFK is the net benefit of vaccinating the number of livestock requiring vaccination on a property.

In the case illustrated in Figure 2, it is uneconomic for farmers with fewer than x_2 animals requiring vaccination on their property to vaccinate these but it is profitable for farmers with more than x_2 animals in need of vaccination to do so. Point F represents a break-even point as far as the profitability of vaccination is concerned. A farmer having x_1 animals to be vaccinated would lose an average of JE

dollars per head by vaccinating whereas one vaccinating x_3 animals would gain KG dollars per animal by vaccinating these.

Evidence from the United States indicates that beef operators with a smaller number of cattle and calves are less likely to vaccinate their herd than those with a larger herd size. The United States Department of Agriculture [10] undertook a survey of the extent to which (depending on the size of herds) beef cattle and calves were vaccinated in 2007 in 24 states. The results are illustrated in Figure 3 and indicate that small herds are much less likely to be vaccinated than larger ones. As was illustrated, in Figure 2, the importance of overhead of fixed costs might be an important factor contributing to this result.

Further discussion of the significant fixed costs for the economics of animal health systems can be found in Tisdell and Adamson [11].

Economics and Externalities (Spillovers) from Livestock Vaccination

Economic theory and the failure to sufficiently control contagious diseases from a social point of view

In the case of contagious livestock diseases, individual owners of livestock are liable to engage in insufficient vaccination of their livestock from a social or collective point of view. These spillovers can be of two types (1) a reduction in the likelihood of livestock being infected on individual properties by a contagious disease as the national or regional proportion of livestock vaccinated increases (this is a positive environmental spillover), or (2) increased access of livestock or livestock products to export markets as a consequence of this coverage. The latter aspect is a pecuniary externality (an economic benefit) to individual owners of livestock which depends on the extent to which a disease is collectively controlled. It has been discussed by Knight-Jones and Rushton [12] in relation to foot and mouth disease. Here, I'll focus on externalities of the first type [see for example, 13, Ch. 3]. When externalities of this type occur, private decisions do not result in the socially optimal proportion of livestock being vaccinated and there is insufficient vaccination of livestock from a collective point of view as has been pointed out by McLeod and Rushton [14] and Knight-Jones and Rushton [12].

Figure 4 illustrates this problem theoretically for an assumed case. The line ABC represents the marginal private willingness of livestock owners to vaccinate their livestock, and line FBDG is the assumed marginal cost of vaccinating livestock. This may be but need not be constant. If x represents the proportion of the national or the regional number of livestock vaccinated, private decisions would result in x_1 of these animals being vaccinated. At this level, the private marginal economic benefit from vaccination equals its marginal cost.

Given that the probability of infection of livestock held by owners is likely to fall as the percentage of animals vaccinated regionally or nationally rises, the social marginal economic benefit from vaccinating livestock exceeds the private marginal economic benefit. The size of the marginal spillover benefit in dollar terms is equal in this illustrative case to the difference between line ABC and DEF. The net social benefit from vaccinating livestock nationally or regionally reaches a maximum when the percentage, x_2 , of this livestock is vaccinated. At x_2 , the social marginal cost of vaccinating livestock equals the marginal case of doing so. The social economic gain from the increase in vaccination covering from x_1 to x_2 is equal to the area of the hatched triangle. Other things held constant, this gain will be larger the greater is the spillover effect. The dotted area is equal to the spillover of economic benefits generated by private decision making.

Note that the slope of line ABC is likely not to be independent of the number of animals vaccinated regionally or nationally. As the probability of infections decline due to more widespread vaccination, this line will be steeper than if it were independent of x . In expression (2) for example, p will decline as more animals are vaccinated regionally or nationally.

Policies to increase vaccination coverage

When externalities or spillovers for vaccinating livestock are important, there can be a case for the adoption of public policies to increase the extent to which livestock are privately vaccinated [14, pp. 319-326]. For example, the government may make vaccination freely available or subsidize it. The former is more likely to occur if vaccination against a particular livestock disease is compulsory. Free vaccination is available in some developing countries for the control of priority livestock diseases. However, the extent to which livestock are vaccinated as a result of such schemes depends on the availability of veterinary services and vaccines.

It is also possible to make vaccinations to control particular diseases compulsory with penalties for non-compliance. However, this may not be politically practical and in some developing countries, because poor owners of livestock may find it difficult (if not impossible) to comply with regulations of this type.

Who Gains Economically from the Vaccination of Livestock?

The use of effective vaccines to control livestock diseases usually results in a reduction in the cost of production of livestock products

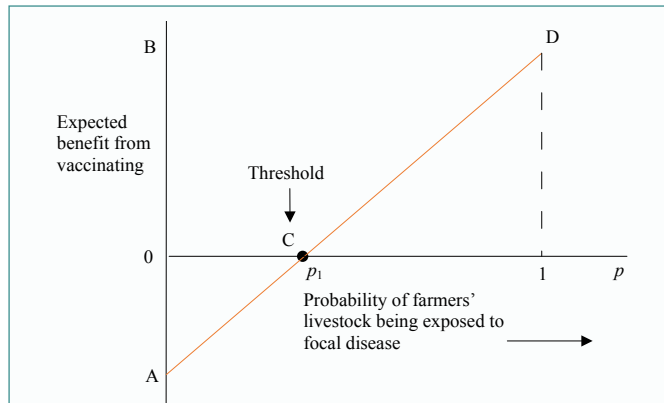


Figure 1: An illustration of the expected profitability of a farmer vaccinating his/her livestock as a function of the likelihood of their exposure to a focal disease, other things held constant.

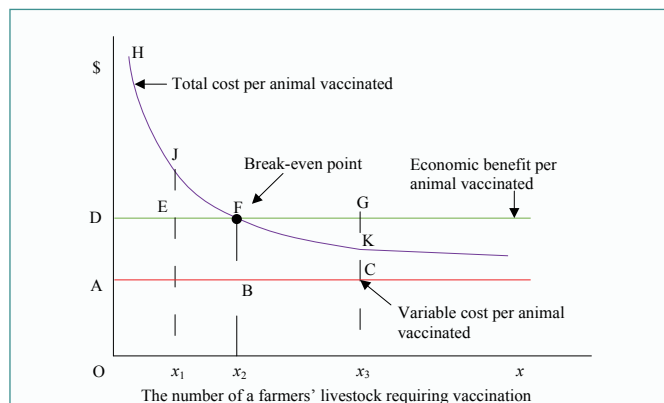


Figure 2: An illustration showing that significant overhead costs of vaccinating livestock on a property can make it uneconomic for farmers with fewer livestock to vaccinate their animals.

and increases their supply. The question arises of to what extent do livestock producers benefit economically (if at all) as a result of this adoption? The predominant view presented in the economic literature has been that suppliers of livestock products will have an increase in the amount of their producers' economic surplus, except in the special case where the demand for livestock products is perfectly inelastic. In the latter case, the predominant economic view is that the amount of their producers' surplus remains constant after the market adjusts to the increased supply. In virtually all cases, the increased supply results in a reduction in the price of livestock products and the economic surplus obtained by consumers of these products rises. In every case, consumers' surplus plus producers' surplus increases when the cost of production of livestock products fall. Consequently, there is an overall net social economic benefit. However, when both producers and consumers gain economically, the distribution of the overall gain is likely to be uneven. For example, for a given market supply curve, the relative gain to producers declines when the market demand curve for livestock products is more inelastic [15, p. 8].

However, it is not always appreciated that the level of producers' surplus can actually fall as a result of reduced costs, for example, due to the more widespread adoption of vaccination of livestock. On the other hand, a reduction in consumers' surplus never occurs – it usually rises as a result of the reduced costs of production.

Otte and Chilonda [15] analyse the economic gains to consumers and producers resulting from increased vaccination of livestock by assuming that the market supply curve of livestock product shifts down by a constant. However, it may not shift by a constant. When it shifts down, it is also possible for its slope either to increase or decrease. In the former case, producers' surplus may actually fall, as was pointed out by Duncan and Tisdell [16]. The more inelastic is the demand for the market supply of the livestock product, the more likely producers' surplus will decline in this case.

If it does, it may be considered to be unfair for livestock producers to either have to pay for research and development of a vaccine or to be mandated to use a vaccine without being financially compensated for doing so.

Figure 5 provides an example of the effects on the level of producers' surplus of different types of shifts in industry supply curve of a livestock product as a result of vaccination. For illustrative purposes, the industry demand curve is shown as being perfectly inelastic and is indicated by the vertical line BEM. It is supposed that in the absence of vaccination, the industry supply curve is as indicated by the line ABS_1 . Market equilibrium is established at point B and the price of the livestock product is equal to OC. Producers' surplus is equal to the area of triangle ABC.

Now suppose that the supply curve moves downwards by a constant amount so that after vaccination the new industry supply curve becomes DES_2 . The amount of producers' surplus then remains unchanged. After this shift, the amount of producers' surplus equals the area of triangle DEF. This is the same as initially because both the bases and heights of triangle ABC and DEF have the same length. However, the amount of this surplus rises if the supply curve shifts to GES_3 , a case in which the supply curve becomes steeper. The area of triangle DEF exceeds that of triangle ABC because the length of the base of triangle GEF exceeds that of triangle ABC and their heights are the same. The surplus is larger by an amount equivalent to the hatched area. On the other hand, if the supply curve shifts to DES_4 , a

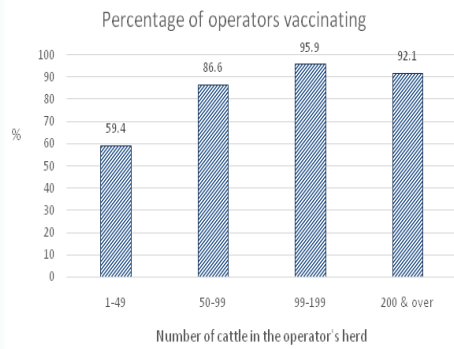


Figure 3: Vaccination coverage of beef cattle in the United States in 2007 by number of cattle in the herds of operators. Source: Based on Table 1. United States Department of Agriculture [10].

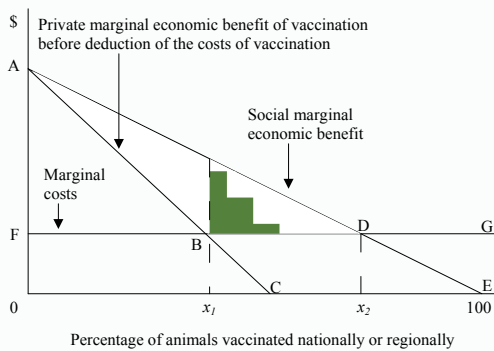


Figure 4: As is illustrated, in the case of contagious livestock disease, private decisions about vaccination of livestock are liable to result in the proportion of animals vaccinated being less than is socially optimal. See the text for the explanation.

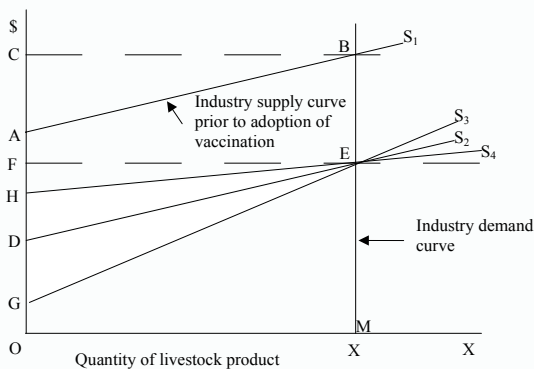


Figure 5: An illustration of the possible impacts of livestock vaccination on the level of producers' surplus. See explanation in the text.

case in which the industry supply curve becomes less steep, producers' surplus falls. This is because the length of the base of triangle HEF is less than that of triangle ABC but the height of both triangles are the same. The reduction is equivalent to the area of the dotted triangle.

Discussion

The economic modeling applied in this article is as was pointed out previously, based on the assumption that the main aim of owners of livestock is to maximize their profit from their husbandry. It was also supposed that they are reasonably well informed about the profitability or otherwise of vaccine use. In practice, imperfect

knowledge can be a major problem and particularly in some societies, not all livestock owners may be motivated to maximize their profit [6,7]. Nevertheless, profit maximization is likely to be a dominant motivator in the management of livestock in countries and regions where the market system is well established. This is especially likely to be so in higher income countries but possibly less so in Third World countries. Therefore, socioeconomic models need to be revised to reflect different regional circumstances. Models that are applicable in developing country situations may not, for example, be appropriate to the circumstances prevailing in more developed countries.

Surprisingly there seems to be many more scholarly articles available which take account of social and economic influences on the adoption of livestock vaccines in developing countries than exist for this topic for more developed countries. The topic needs more attention in the case of higher income countries. In addition, future studies should consider the role which the indebtedness of livestock enterprises plays in their willingness to adopt vaccines and the relevance of their financial liquidity. Furthermore, many livestock owners may prefer to earn a steady stream of income or profit rather than maximize the net present value of their enterprises. In this case, if the use of vaccines foster this objective, they are more likely to be adopted; but if vaccination puts the steadiness of this stream at risk, they may be less inclined to use them. Also those livestock enterprises in higher income countries which depend more heavily on loans (that is, are highly geared financially) may be more likely to vaccinate their livestock if this improves the prospect of them meeting their obligations to lenders. This would be a precautionary strategy. There appears to have been no studies of these types of influence on the adoption of livestock vaccines.

Empirical studies of differences in the perceptions of scientists and livestock owners about the value of livestock vaccination are also useful. A study of this kind was completed in India by Rathod et al. [17]. They found that only 61.4% of the 390 dairy farmers surveyed considered vaccination of their livestock to be profitable whereas 100% of the scientists surveyed believed that this vaccination was profitable. They listed the major problems mentioned by farmers in relation to vaccinating dairy cattle. These include possible side effects of some vaccines (e.g., reduced milk production, and vaccinated animals becoming disease affected). Other problems included poor infrastructure to store vaccines, non-availability of veterinarians or skilled staff to administer vaccines and lack of knowledge about vaccines.

However, we do not know why this lack of knowledge existed. In some cases, it can be unprofitable for livestock owners to seek a lot of knowledge about particular vaccines because they know from their limited information that they would not adopt them. Battacharya et al. [9] found for example, that cattle rangers with smaller herds were less well informed about the *Trichomonias* vaccine than were those with larger herds and stated that this should be a matter for further investigation. In some cases, the estimated economic value of additional information about a vaccine exceeds the extra costs of obtaining it. This would be so if limited information is sufficient to conclude that vaccination would be uneconomic or otherwise [see for example, 18, Ch. 1].

It also needs to be remembered that vaccination is not the only possible response to many livestock diseases. Other than vaccination, possibilities can include the adoption of measures to reduce the likelihood of an animal being subjected to disease and treatments if

an animal should become infected. The economic value of all these possibilities should be considered to determine overall decisions about the control of livestock diseases.

Zoonoses also add an extra dimension to the economic and social evaluation of the control of animal diseases. They raise difficult questions about how the economic value of reducing human mortality and morbidity from animal diseases should be calculated and additional public policy issues which could not be covered in this article. In addition, this article has not considered how the economic value of sustaining the health of pets could be evaluated and issues associated with the healthiness of wildlife.

Conclusion

This discussion has indicated that the economics of vaccinating livestock can be complex and that there is a need for much more research into this subject and the topic of animal health economics generally. From a policy point of view, it is important that the studies of natural scientists about animal health (including those involving the vaccination of animals) be supplemented by economic and social studies.

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